Muon Backgrounds with Reduced Shielding

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SiD Workshop
Fermilab
April 9-11, 2007

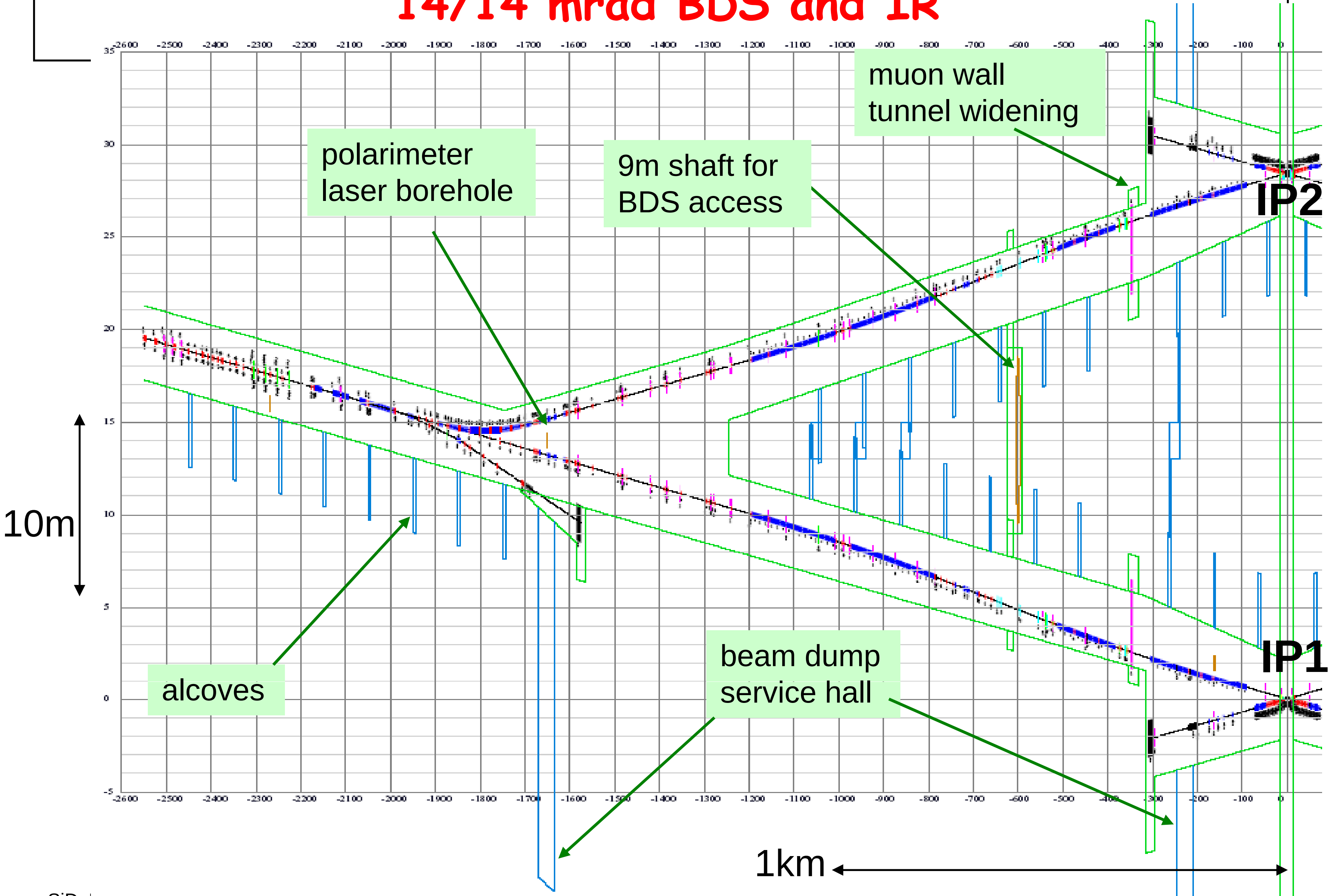
OUTLINE

- Beam-Beam and Machine-Related Backgrounds.
- Detector Tolerable Limits.
- Particle Flux, Hit Rate and Occupancy in Detector.
- Suppressing Muon Backgrounds in Detectors.
- Two Walls *vs* Single Wall *vs* Doughnuts.

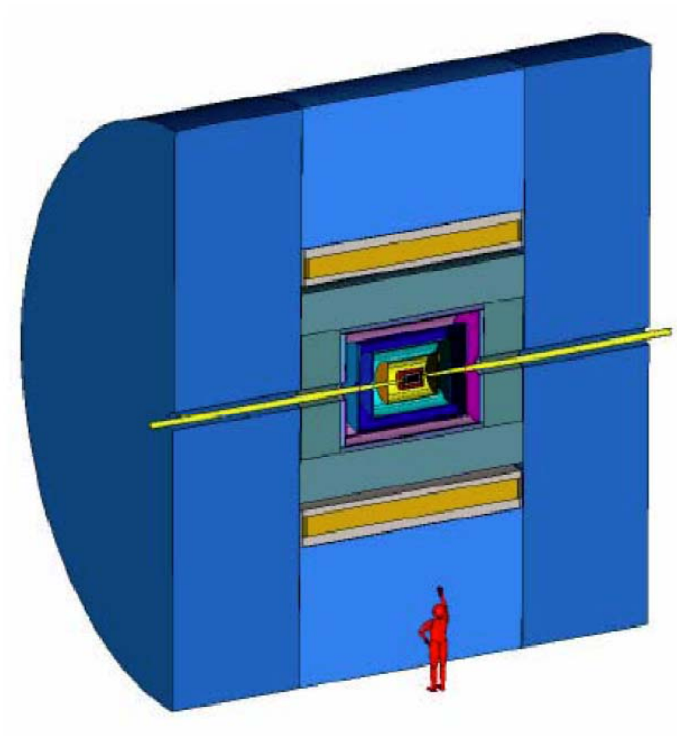
BACKGROUNDS AND IR/DETECTOR DESIGN

The high physics potential of the ILC is reached only if a high luminosity of e^+e^- collisions in the TeV range is achieved (say, 2×10^{34} cm^{-2} s^{-1}). The overall detector performance in this domain is strongly dependent on the background particle rates in various sub-detectors. The deleterious effects of the background and radiation environment produced by the accelerator and experiments have become very important issues in the Beam Delivery System (BDS), Interaction Region (IR) and detector design and development.

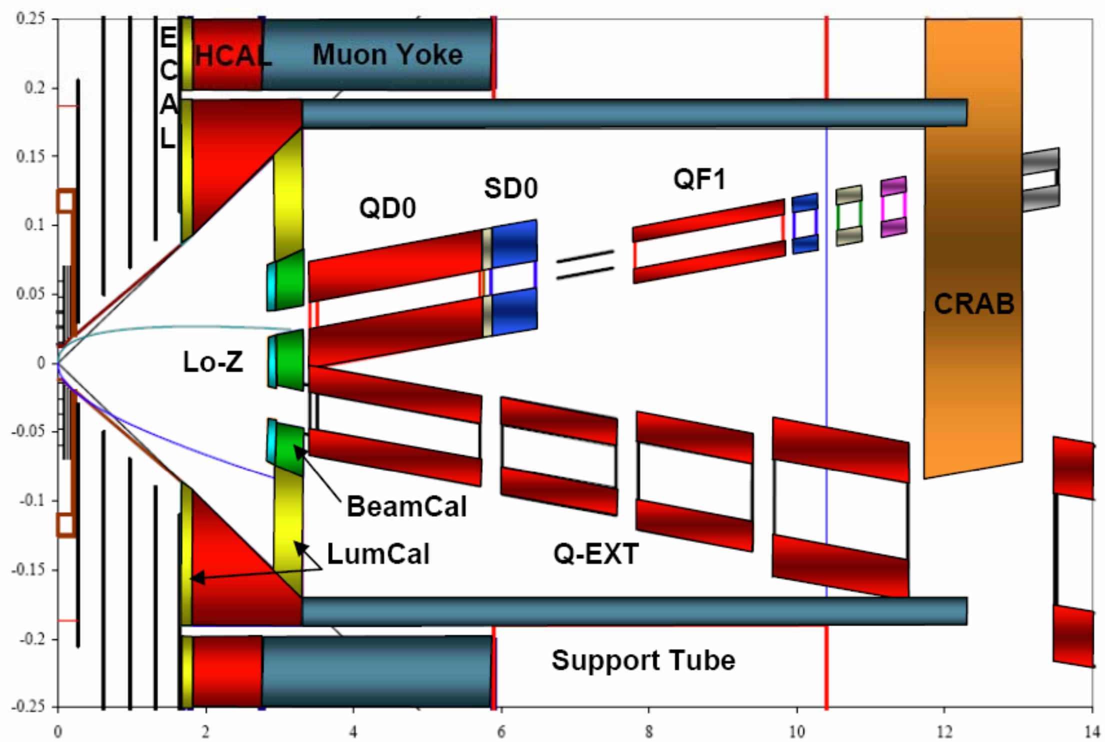
14/14 mrad BDS and IR



SiD AND MACHINE-DETECTOR INTERFACE



ILC "compact" detector SiD
with 5-Tesla solenoid field



BACKGROUNDS AND DETECTOR PERFORMANCE

Two sources

1. **IP backgrounds:** Particles originated from the interaction point (IP) – beam-beam interaction products and collision remnants.
2. **Machine backgrounds:** Unavoidable bilateral irradiation by particle fluxes from the beamline components and accelerator tunnel.

Backgrounds affect ILC detector performance in three major ways:

- Detector component radiation aging and damage.
- Reconstruction of background objects (e.g., tracks) not related to products of e^+e^- collisions !!!
- Deterioration of detector resolution (e.g., jets energy resolution due to extra energy from background hits).

BEAM PARAMETERS

- 250-GeV
- 5 trains per second
- 2820 bunches in each train
- 300 ns between bunches
- 199 ms between trains
- Train length 868 μs
- 2×10^{10} positrons/electrons per bunch
- Luminosity 2×10^{34} cm^{-2} s^{-1}

BACKGROUND TOLERABLE LIMITS

Calorimeter, tracker and vertex detectors: in smallest element, ***occupancy*** ≤ 1%.

To avoid ***pattern recognition*** problem in tracker, hit density from charged particles should be ≤ 0.2 hit/cm²/bunch.

To avoid ***pile-up*** problem (from previous BX !) in tracker, hit density from charged particles should be ≤ 0.2 hit/mm²/train.

Muon system: the RPCs (sensitive media) need 1 ms to re-charge a 1 cm² area around the avalanche, therefore, the hit rate in excess of 100 Hz/cm² would result in an unmanageable dead time. With typical 80 sensitive layers in a Muon Endcap, it corresponds to a muon flux at its entrance of about 1 μ/cm²/s.

Bethe-Heitler Muons, Hadrons etc.

About 10^{-4} muons are generated per 250-GeV electron hitting material (limiting apertures, residual gas) which – being accompanied by other particles – can reach the IP and create background levels well above the tolerable limits. These are mainly energetic muons from Bethe-Heitler process $\gamma Z \longrightarrow \mu+\mu-Z$.

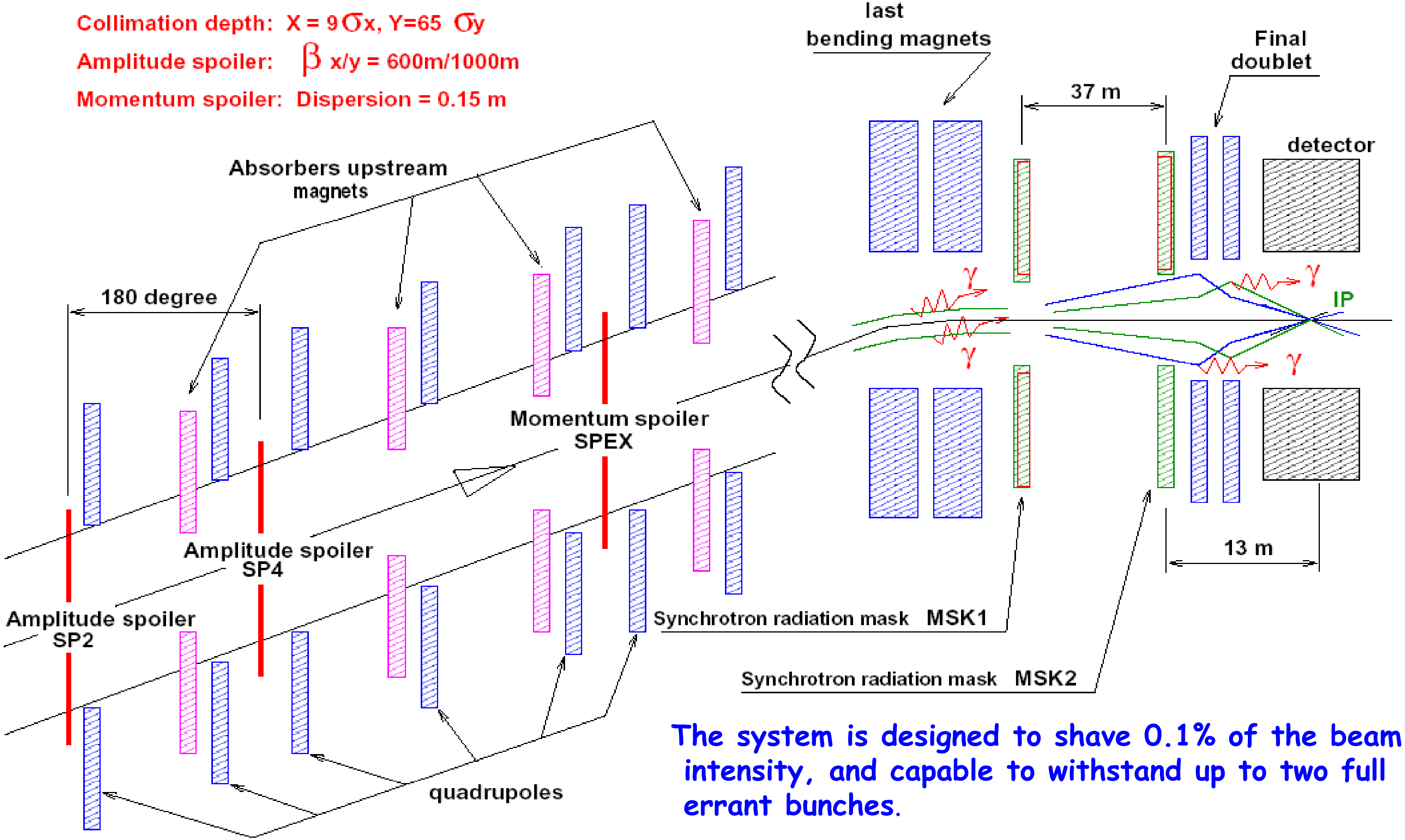
Also, muon pairs from e^+e^- annihilation, hadrons from photo- and electro-nuclear inelastic interactions, and decay products of all unstable particles.

Make these limiting apertures (collimators) as far from IP as possible. Suppress muon flux far from IP by thick magnetic walls or doughnuts.

Studied in very complex realistic BDS modeling.

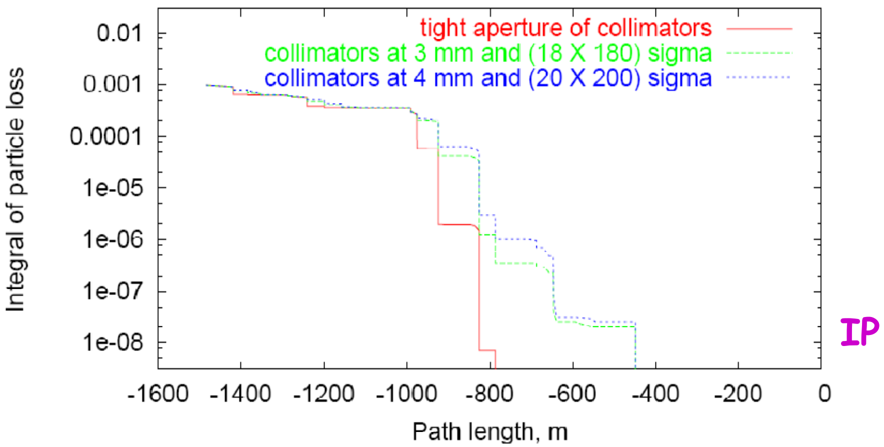
BDS COLLIMATION SYSTEM

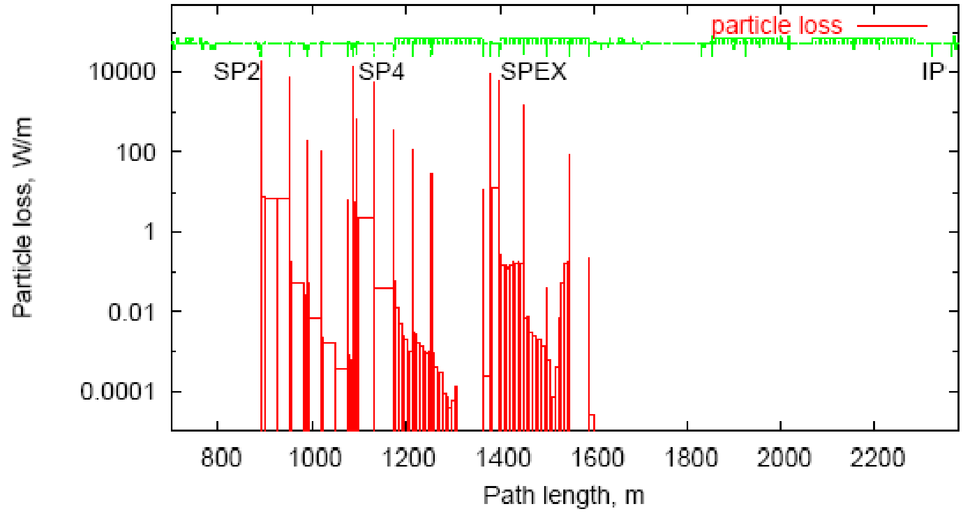
Collimation depth: X = 9 σx, Y=65 σy
Amplitude spoiler: β x/y = 600m/1000m
Momentum spoiler: Dispersion = 0.15 m

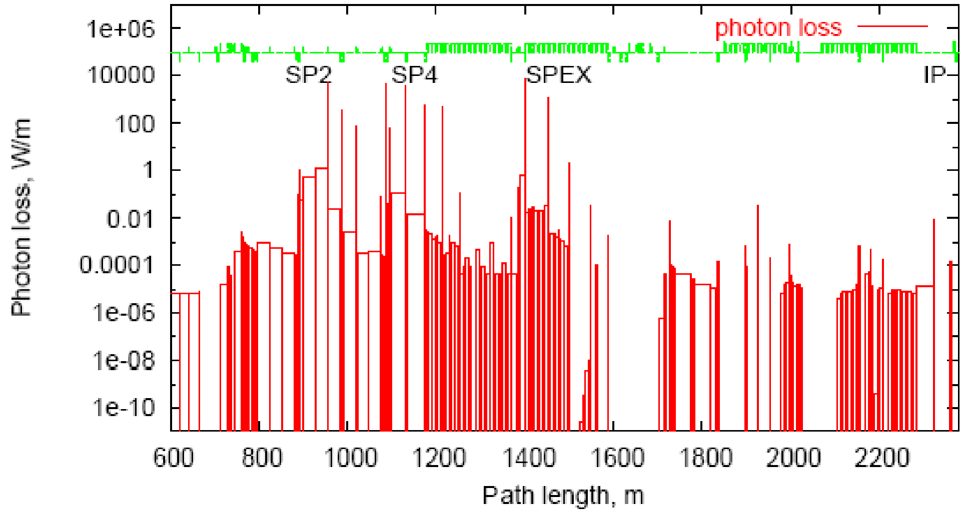


The system is designed to shave 0.1% of the beam intensity, and capable to withstand up to two full errant bunches.

COLLIMATION EFFICIENCY AND BEAM LOSS

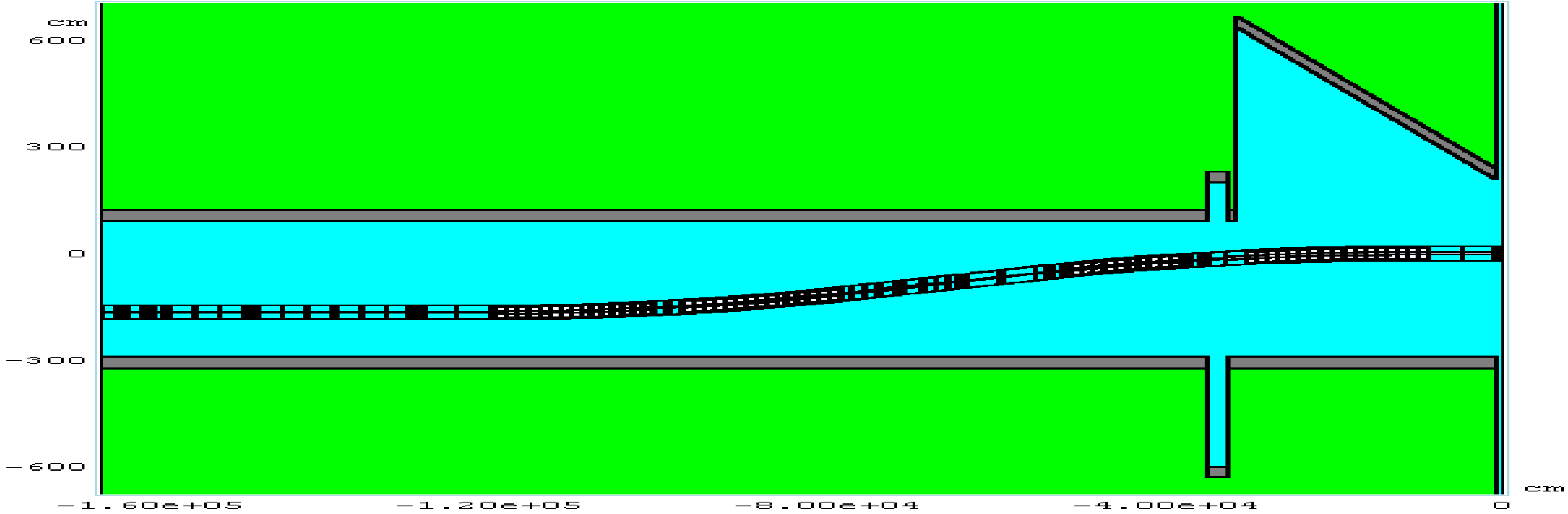




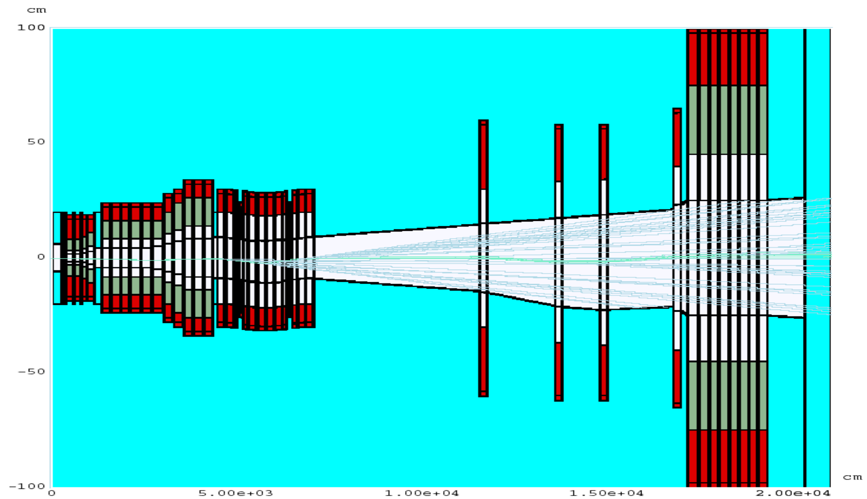


Collimation efficiency defined here as a fractional loss of halo charged particles, integrated back starting the IP and normalized to the nominal bunch charge

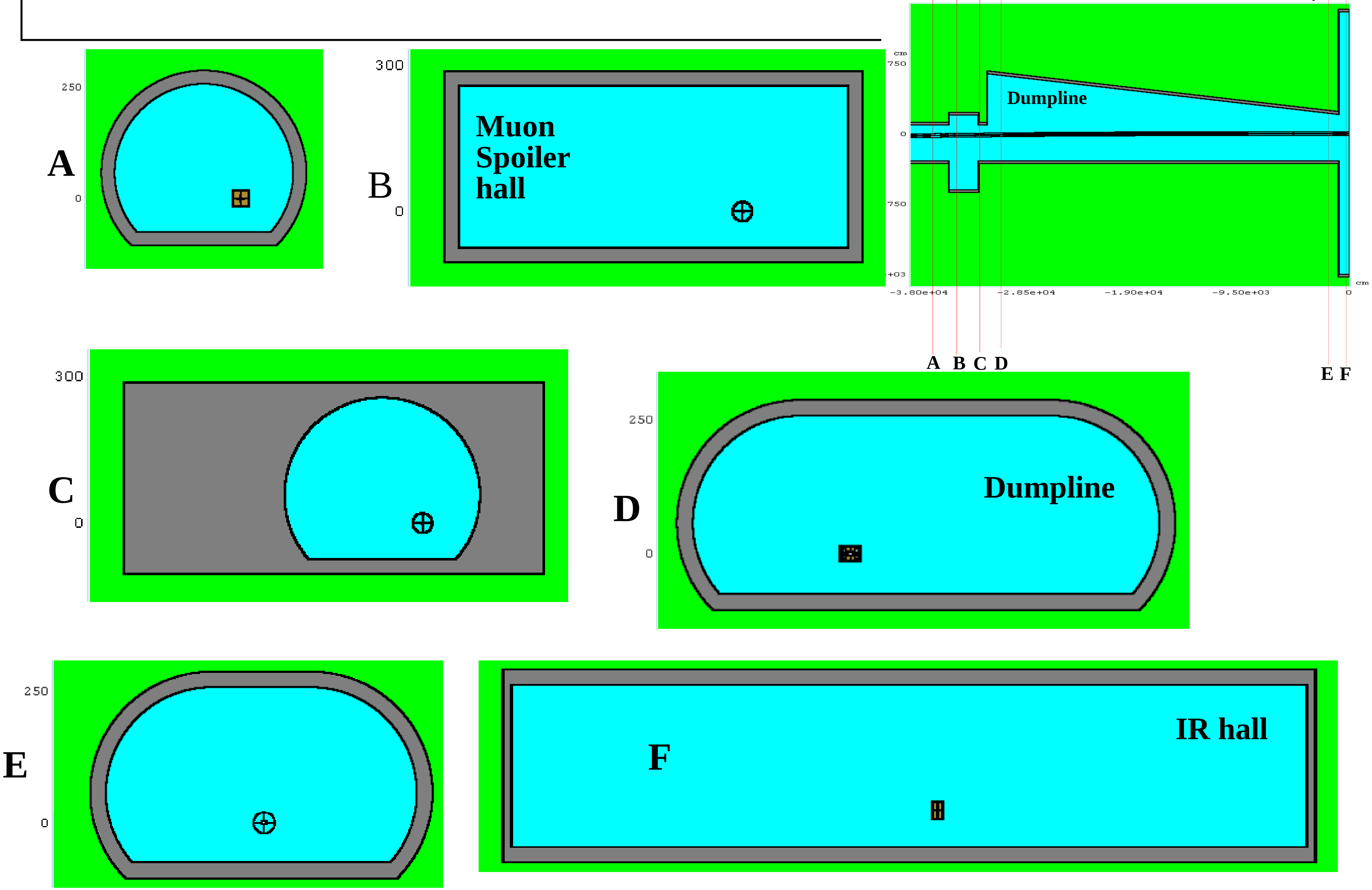
BDIR MARS MODEL: 1700 m BDS, SiD (GEANT4) at IP, followed by 200-m extraction line



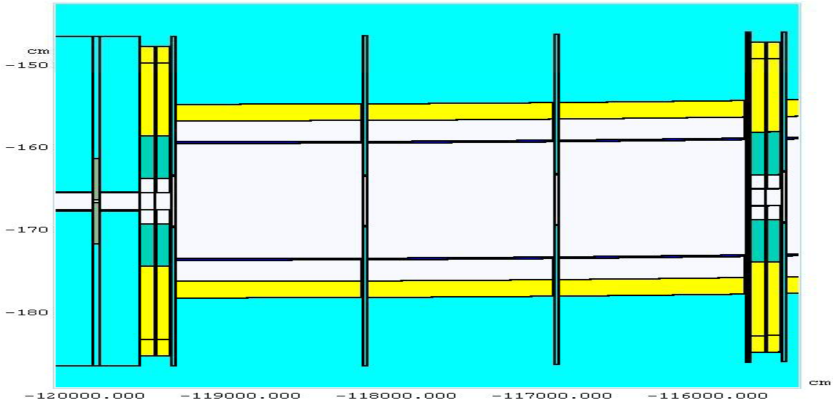
Model includes all magnets, tunnel, concrete walls, dirt, multi-stage collimation system (spoilers, absorbers, protection collimators, and photon masks), muon tunnel spoilers, SiD detector, and extraction line (for high-lum 250-GeV beams).

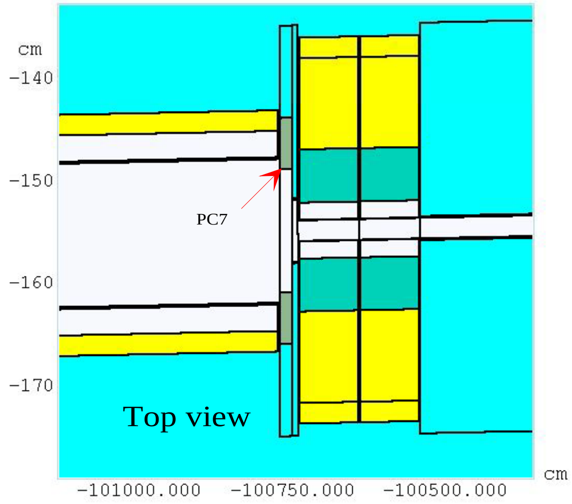


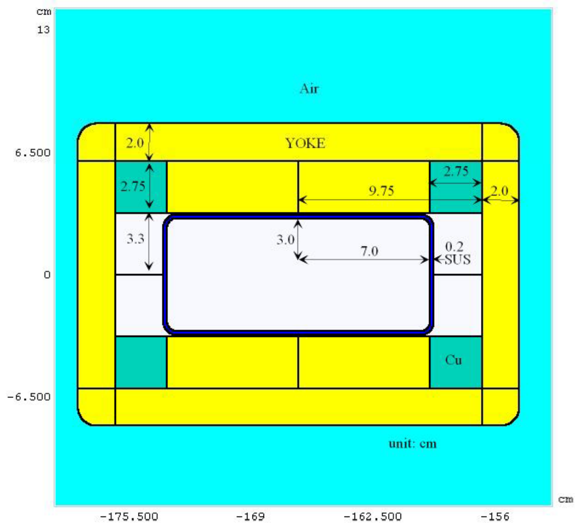
BDS MODEL X-SECTIONS IN MARS15

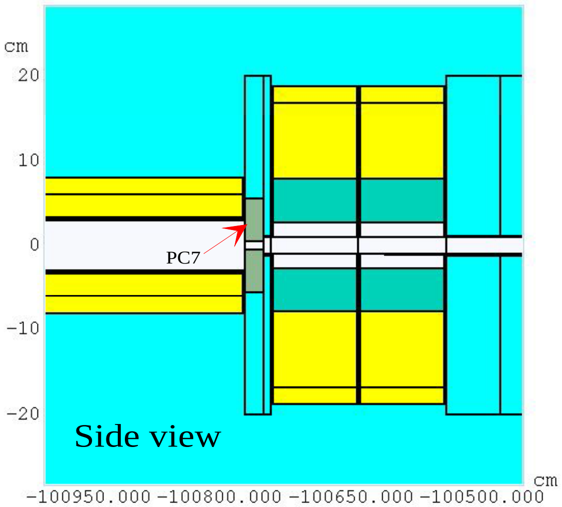


MARS Magnet and PC Geometries









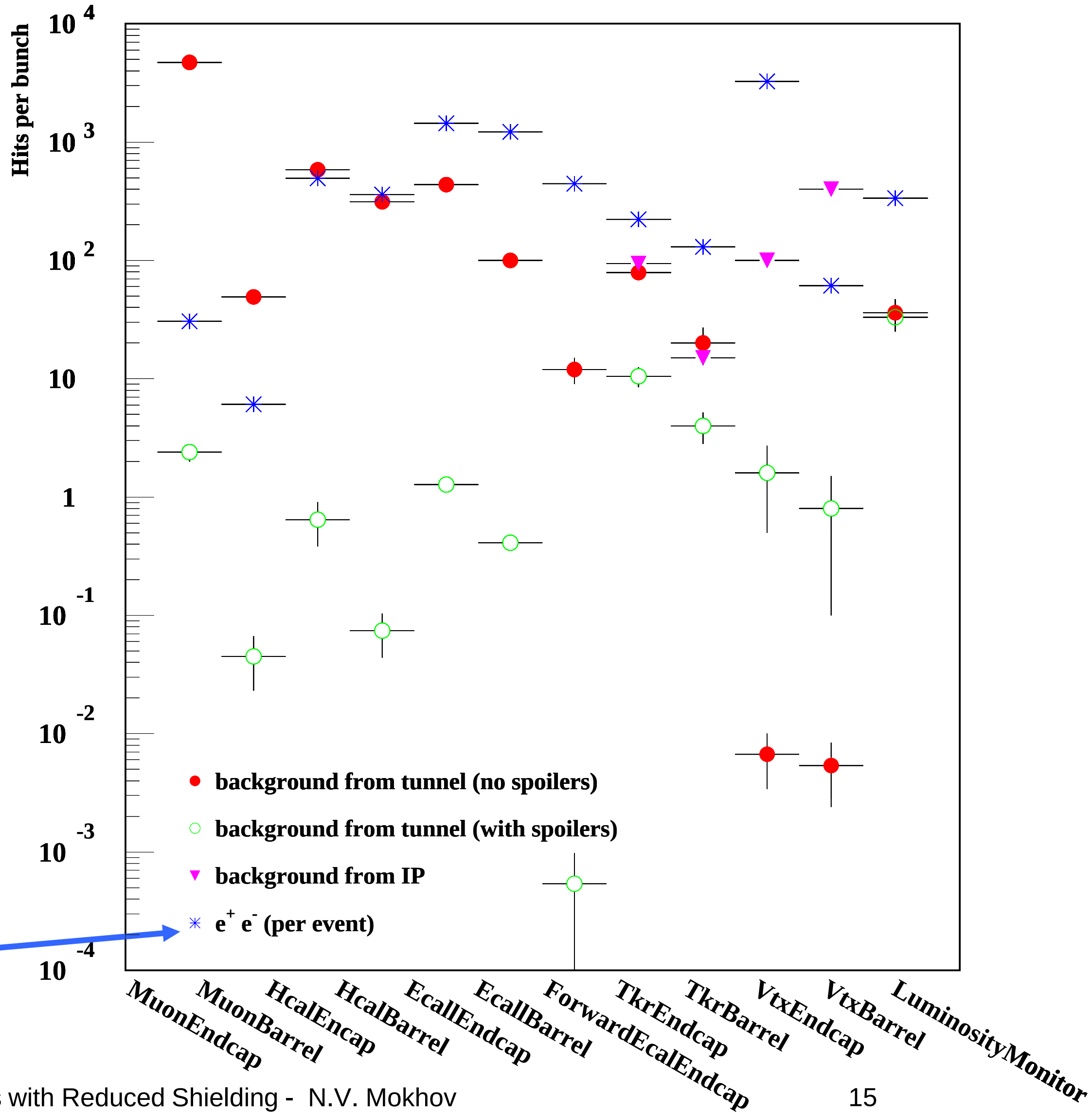
Hit Rates in Detector Subsystems

1. Machine-related background with and without spoilers – STRUCT+MARS15 + SLIC.
   Here – only from e^+ beam.

2. IP-related background – radiative Bhabas from beam-beam interaction and synchrotron radiation from beam. Guineapig + GEANT3

3. $e+e-$ events at 500 GeV- PYTHIA + SLIC

Per e^+e^- event



BDS Induced Detector Backgrounds

Table. 1 : Average number of particles per bunch at the SiD from positron tunnel.

	γ	$\mu^{\pm}$	e^{+}	e^{-}	neutron
With spoilers	2927	0.024	1172	$3.6 \cdot 10^{-4}$	6364
No spoilers	2942	60.4	1095	10	346

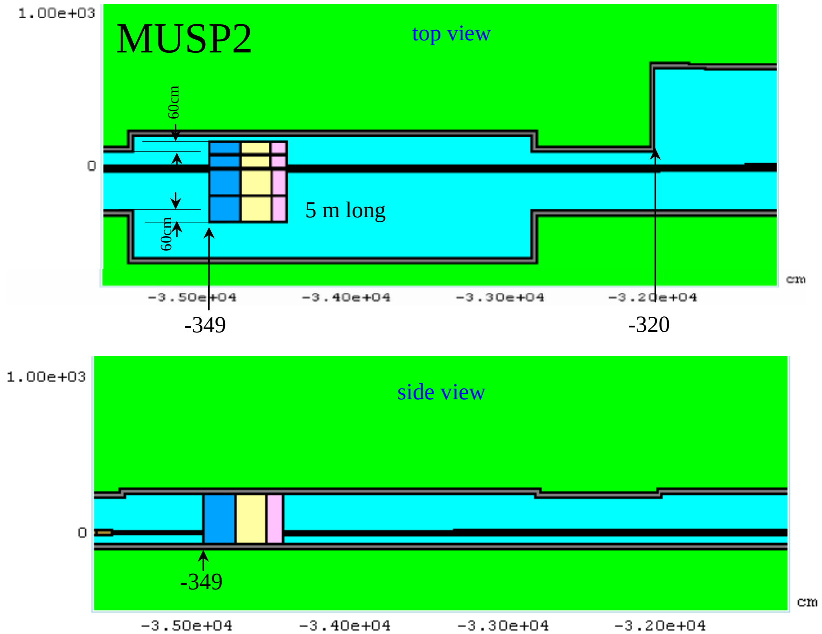
Table. 2 : Average kinetic energy (GeV) of particles at the SiD from positron tunnel.

	γ	$\mu^{\pm}$	e^{+}	e^{-}	neutron
with spoilers	$5.4 \cdot 10^{3}$	38	251	0.13	$1.6 \cdot 10^{3}$
no spoilcrs	$5.5 \cdot 10^{-3}$	28	250	0.19	$7 \cdot 10^{-4}$

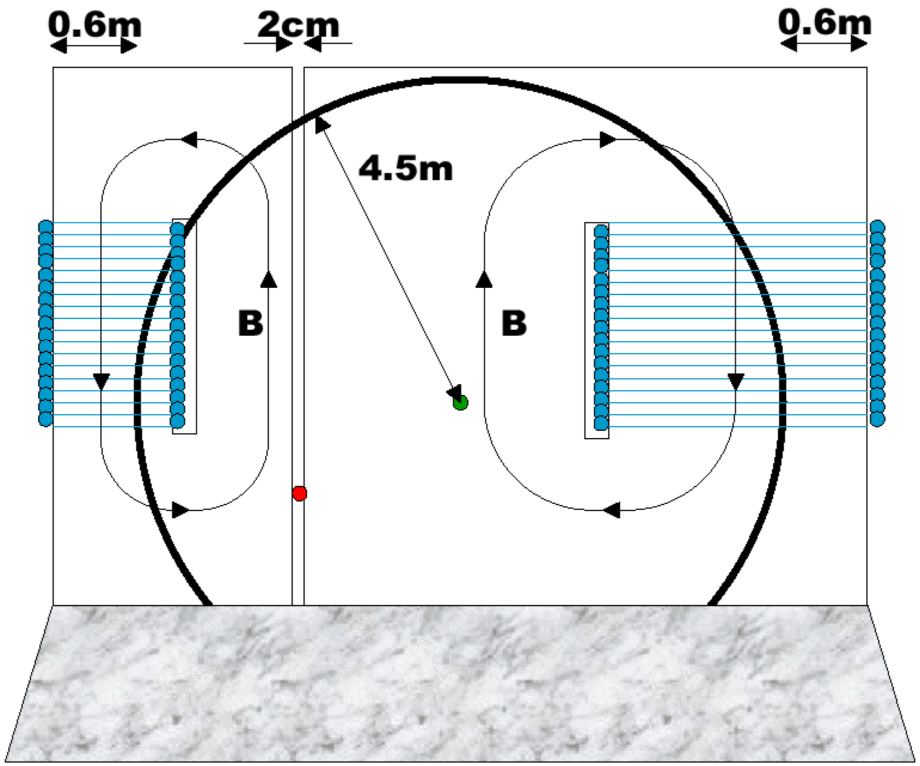
Table. 3 : Contribution of particles from the positron tunnel to hit rates in the SiD sub-detectors without spoilers.

	All hits/bunch	γ %	$\mu^{\pm}$ %	e^{+} %	e^{-} %	neutron %
Muon Endcap	4711	0.2	99.4	0.1	0.3	0
Muon Barrel	49	0	100	0	0	0
Hcal Endcap	584	0	100	0	0	0
Hcal Barrel	314	0	100	0	0	0
Ecal Endcap	435	0	100	0	0	0
Ecal Barrel	100	0	100	0	0	0
FEcal Endcap	12	0	100	0	0	0
Tkr Endcap	79	0	95	5	0	0
Tkr Barrel	20	59	41	0	0	0
Vtx Endcap	$6.7 \cdot 10^{-3}$	0	100	0	0	0
Vtx Barrel	$5.4 \cdot 10^{-3}$	0	100	0	0	0
Luminosity Monitor	36	45	10	45	0	0

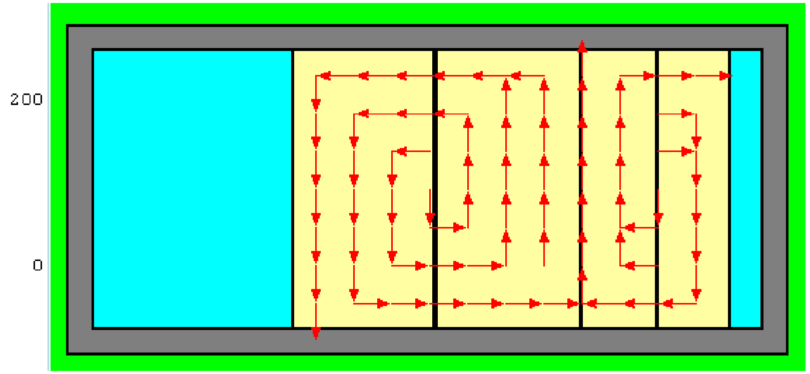
TUNNEL MUON SPOILERS: 9+18 m or 5 m Walls



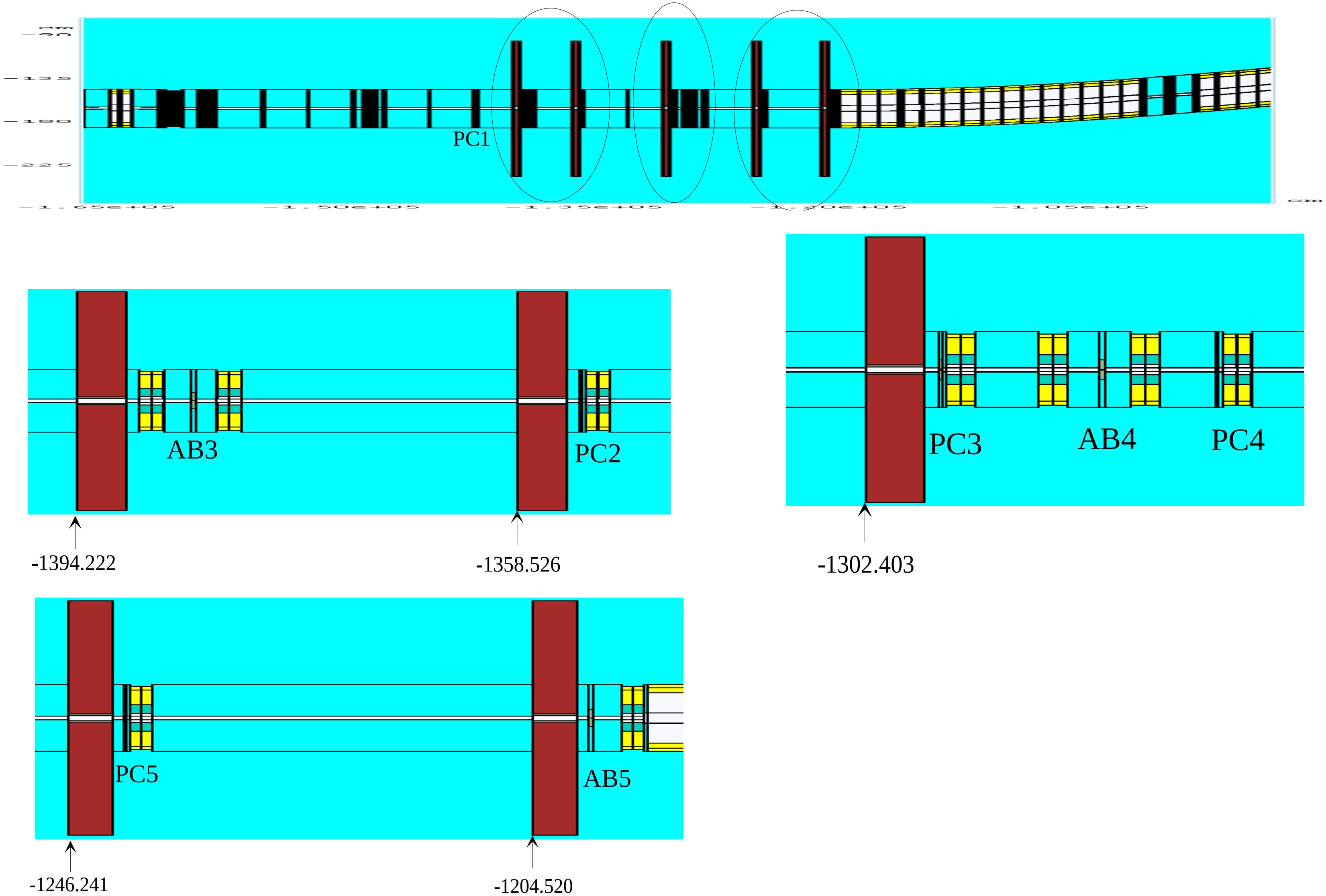
Thick steel 1.5-T magnetic wall sealing tunnel x-section, to spray the muons out of the tunnel



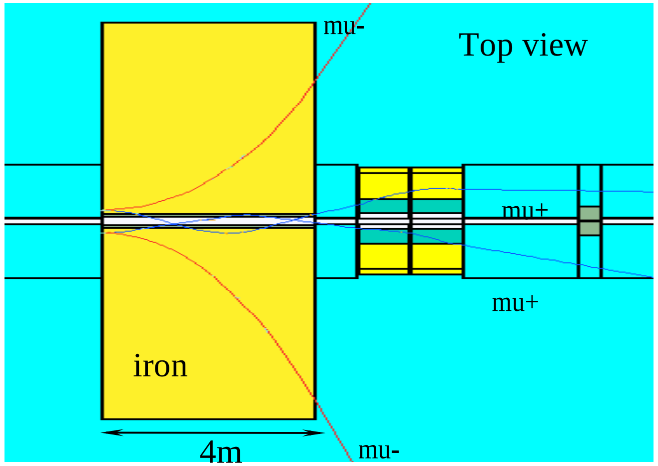
Cross sectional view (looking toward downstream)

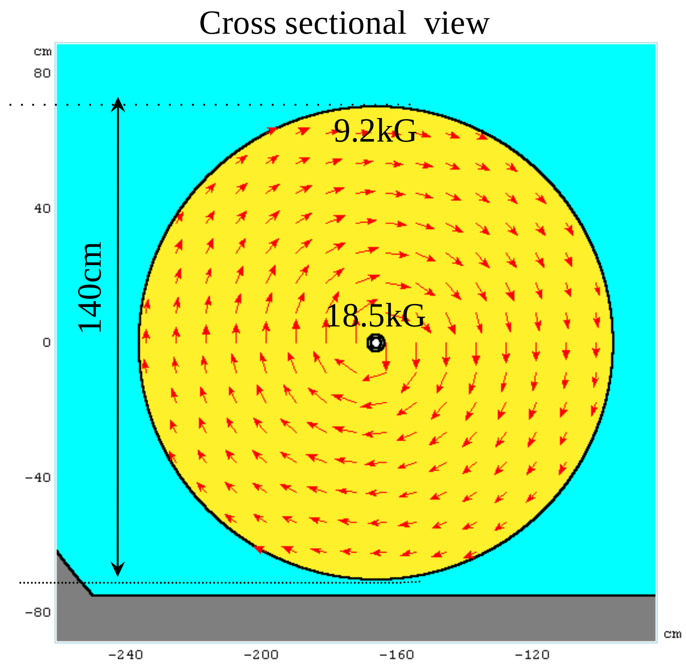


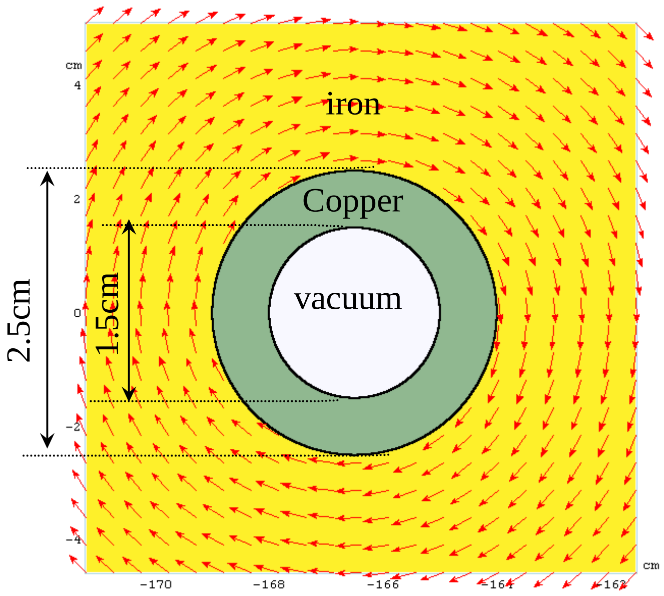
Five 4-m Thick Doughnut Scheme



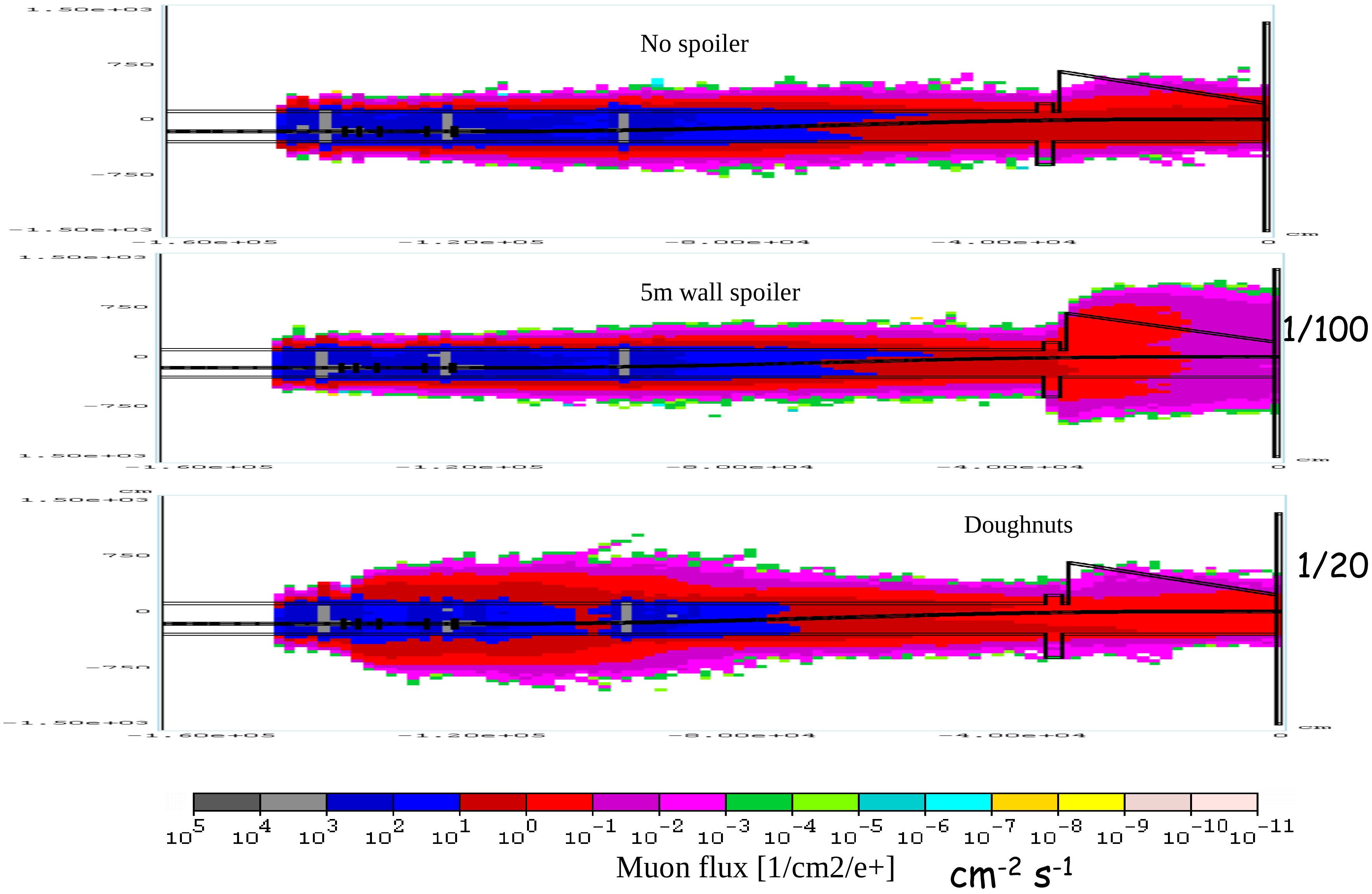
Magnetic Doughnuts



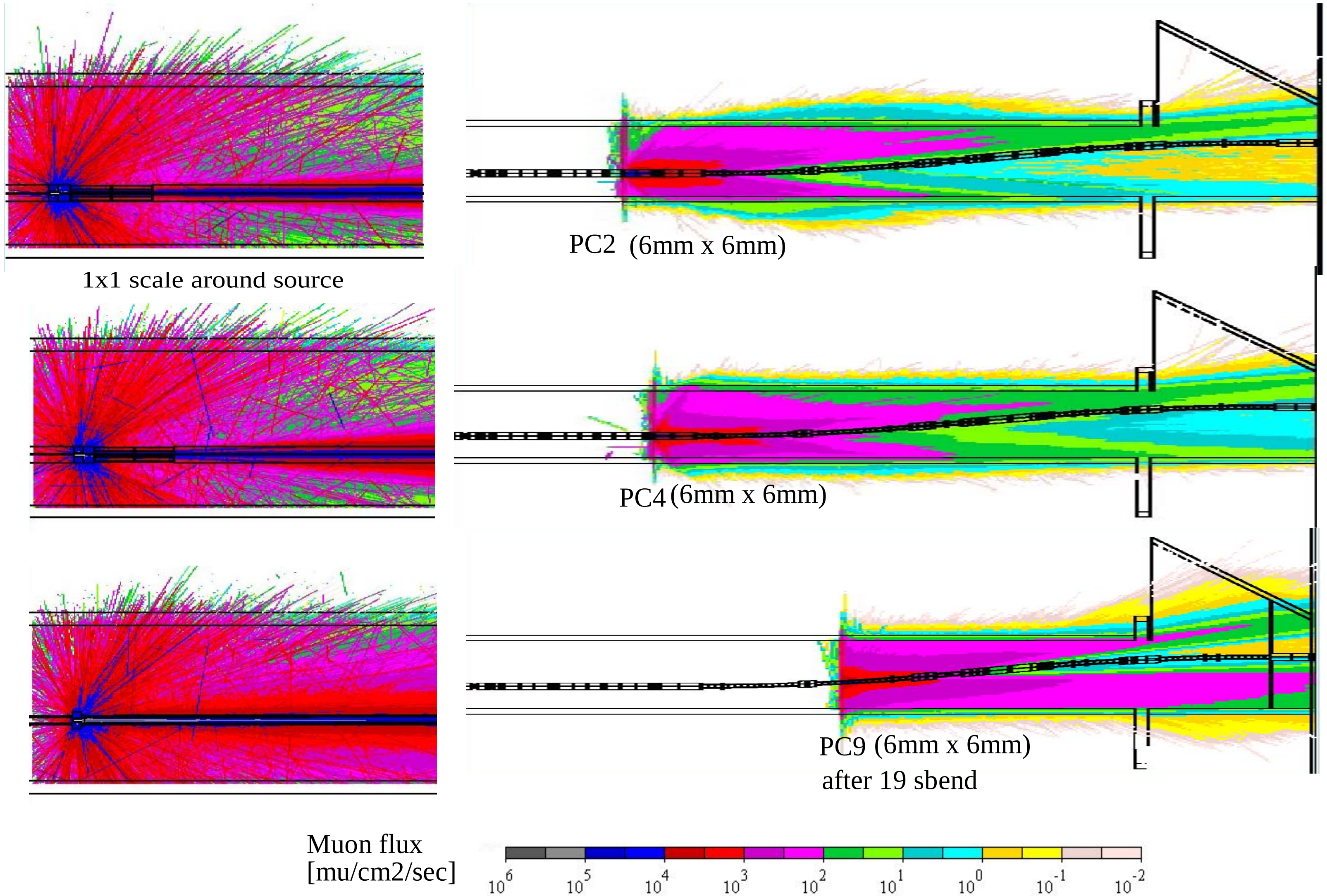




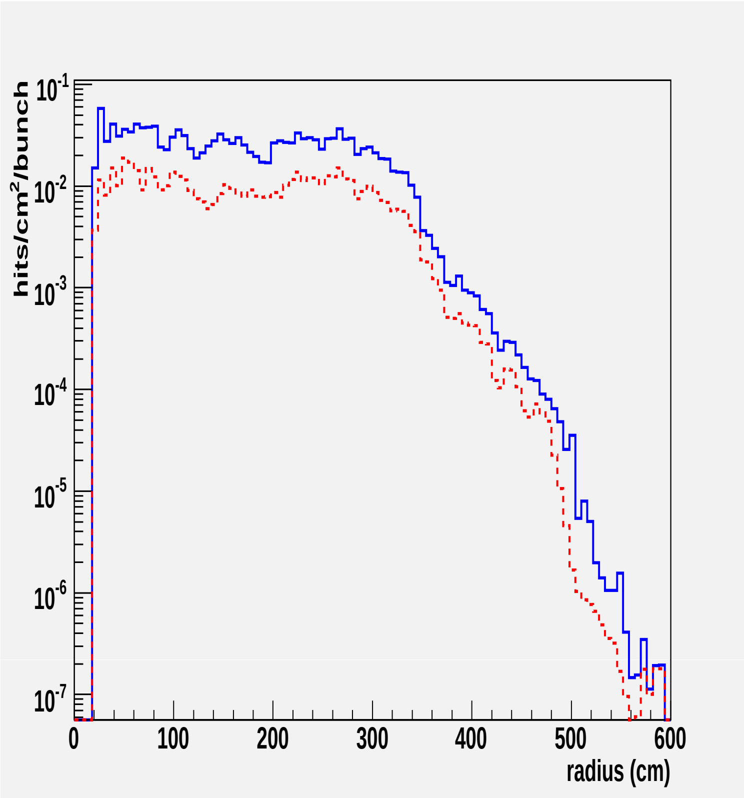
Muon Flux Isocontours

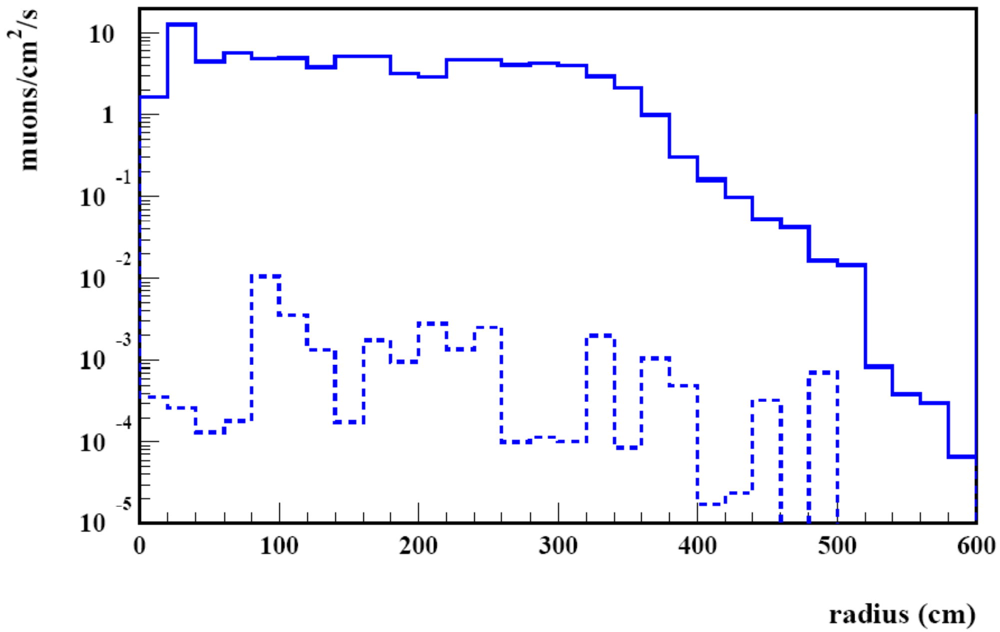


Muon Fluxes from Hottest PCs



Hits in and Flux at Muon Endcap without Shielding

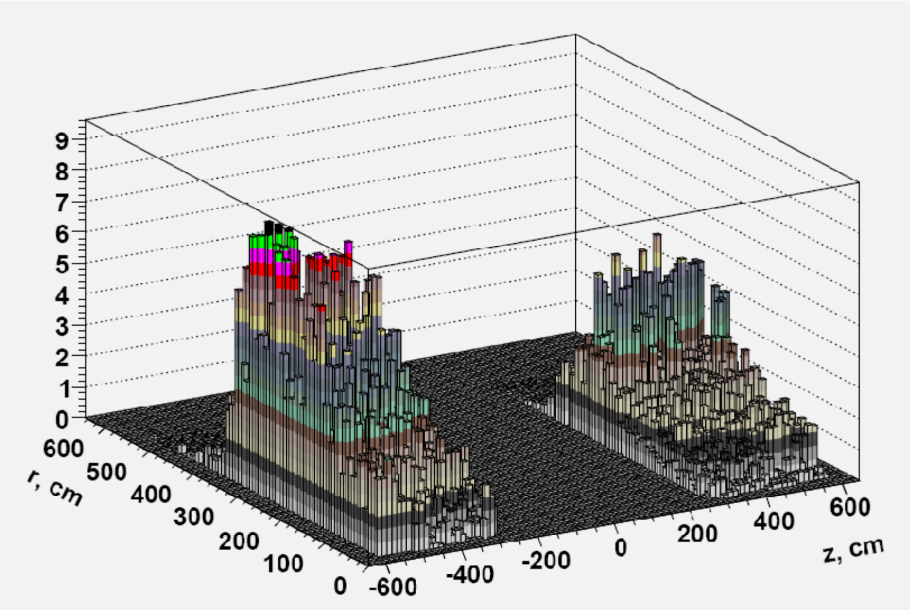




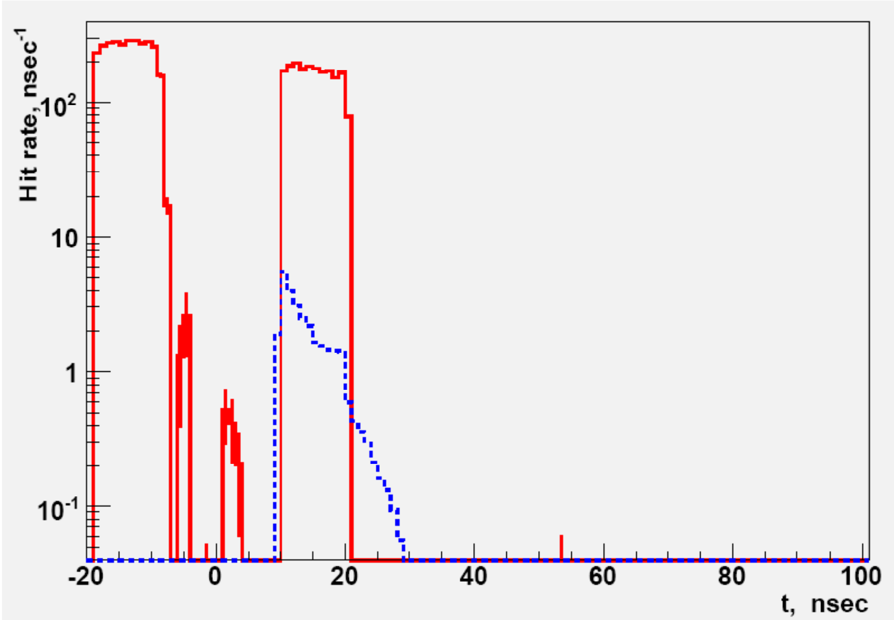
Muon flux (cm^{-2}/s^{-1}) due to both beams:
~4 $cm^{-2}s^{-1}$.
To be compared to the **1 $cm^{-2}s^{-1}$ limit**.
Dashed – with 9 & 18m magnetic walls.

Hits/cm^2/bunch (due to both beams):
400 Hz/cm^2 for 14100 bunch/s.
To be compared to the **100 Hz/cm^2 limit**.
Dashed – after bunch crossing.

Hits in Muon Endcap without Shielding (due to e^+ Beam Only)



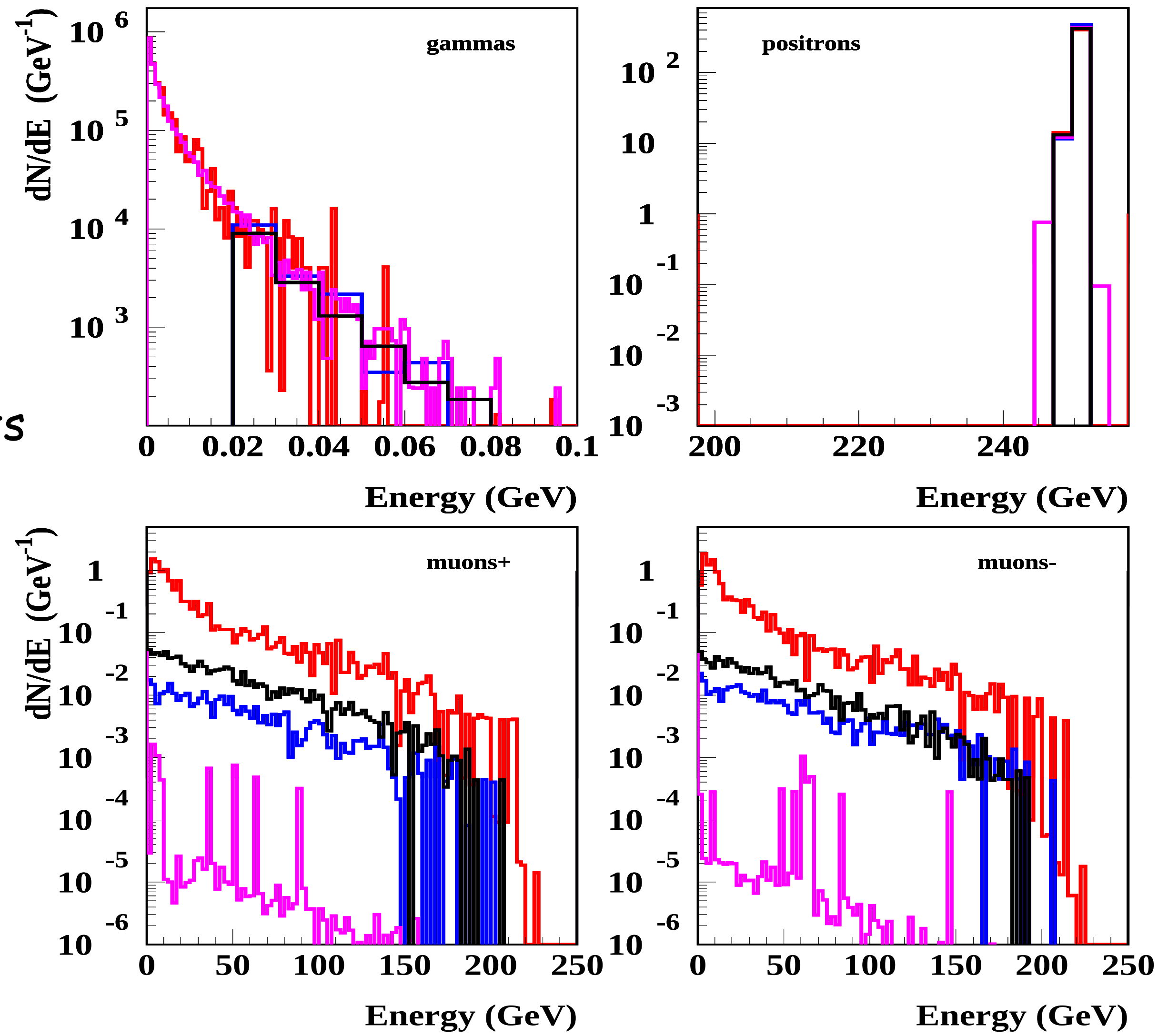
RZ-distribution of hits per bunch.



Hit rate ($nsec^{-1}$). t=0 is bunch crossing.
Dashed line – e+e- events.

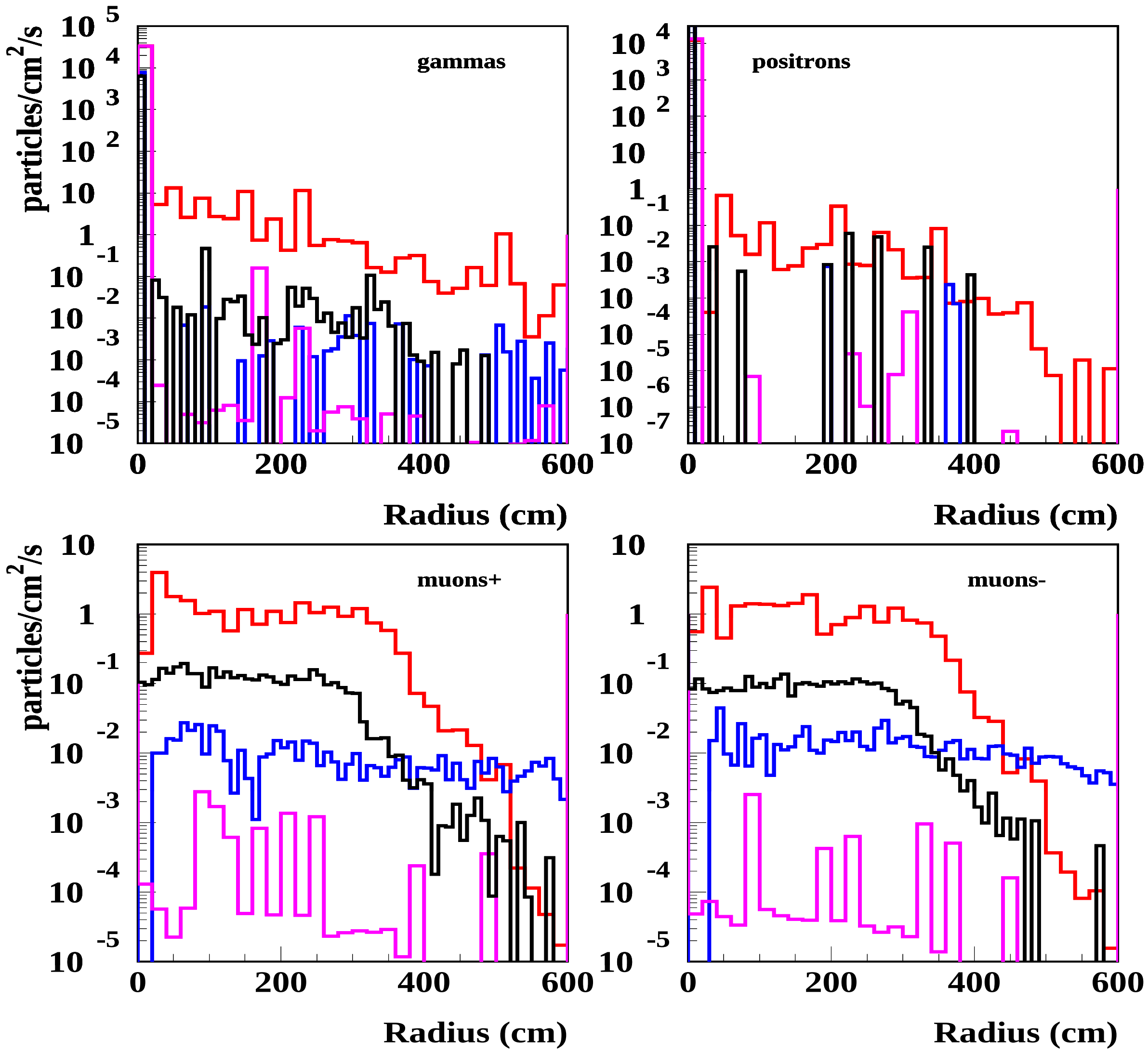
Particle Energy Spectra (per bunch) at SiD from e+ BDS

Red lines: no shielding
Magenta: 9m + 18m walls
Blue: 5m wall
Black: Five 4-m doughnuts



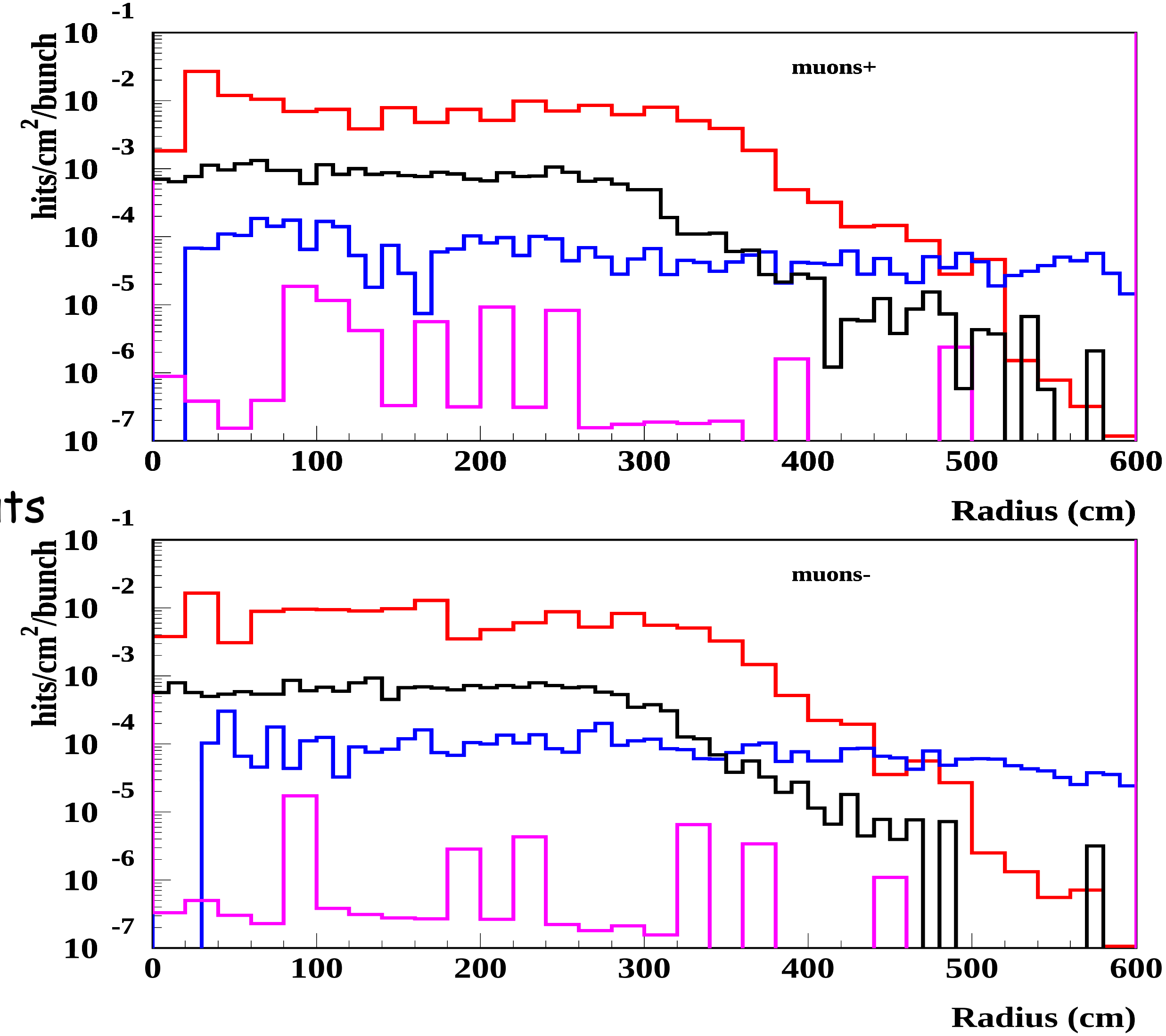
Particle Fluxes ($cm^{-2}s^{-1}$) at SiD from e^+ BDS

Red lines: no shielding
Magenta: 9m + 18m walls
Blue: 5m wall
Black: Five 4-m doughnuts



Hits in Muon Endcap (cm^{-2}/bunch) at SiD from e$^+$ BDS

Red lines: no shielding
Magenta: 9m + 18m walls
Blue: 5m wall
Black: Five 4-m doughnuts



SUMMARY

• 5-m thick tunnel-filling iron magnetic walls at ~350 m from IP (both sides) provide adequate reduction of BDS-originated muon backgrounds at SiD, improving its longevity and performance. They also provide radiation protection needed for work underground when beam is on with two IRs or in a push-pull scenario.

• Five 4-m long 0.7-m radius magnetic doughnuts provide needed suppression of muon fluxes at SiD. An increased scheme (with 7-10 doughnuts) can provide sufficient safety margin. Alternatively, additional shielding wall close to IP would work. Such a wall may be needed anyway to bring the radiation levels in the IR below the regulatory limits with two IRs or in a detector push-pull case.